XLR 600i: Recirculating Ring ArF Light Source for Double Patterning Immersion Lithography

Vladimir Fleurov; Slava Rokitski; Robert Bergstedt; Hong Ye; Kevin O'Brien; Robert Jacques; Fedor Trintchouk; Efrain Figueroa; Theodore Cacouris; Daniel Brown; William Partlo, Cymer Inc.

INTRODUCTION

Double patterning (DP) lithography is expected to be deployed at the 32nm node to enable the extension of high NA (≥1.3) scanner systems currently used for 45nm technology. Increasing the light source power is one approach to address the intrinsically lower throughput that DP imposes. Improved energy stability also provides a means to improve throughput by enabling fewer pulses per exposure slit window, which in turn enables the use of higher scanner stage speeds. Current excimer laser light sources for deep UV immersion lithography are operating with powers as high as 60W at 6 kHz repetition rates. In this paper, we describe the introduction of the XLR 600i, a 6 kHz excimer laser that produces 90W power, based on a recirculating ring technology. Improved energy stability is inherent to the ring technology. Key to the successful acceptance of such a higher power, or higher energy laser is the ability to reduce operating costs. For this reason, the recirculating ring technology provides some unique advantages that cannot be realized with conventional excimer lasers today. Longer intrinsic pulse durations that develop in the multi-pass ring architecture reduce the peak power that the optics are subjected to, thereby improving lifetime. The ring architecture also improves beam uniformity that results in a significantly reduced peak energy density, another key factor in preserving optics lifetime within the laser as well as in the scanner. Furthermore, in a drive to reduce operating costs while providing advanced technical capability, the XLR 600i includes an advanced gas control management system that extends the time between gas refills by a factor of ten, offering a significant improvement in productive time. Finally, the XLR 600i provides a novel bandwidth stability control system that reduces variability to provide better CD control, which results in higher wafer yields.

DOSE STABILITY

The XLR 600i is a derivative of the XLR 500i, that was introduced in 2006 to address immersion lithography requirements for improved dose stability and lower operating costs[1]. Significant improvement in energy stability has been attained with the enhanced optical configuration. The XLR power amplifier is aptly called a power 'regenerative' amplifier (PRA) due to the fact that each pulse experiences multiple passes and is successively amplified. We denote the system utilizing a PRA amplification stage as a MOPRA (Master Oscillator Power Regenerative Amplifier).

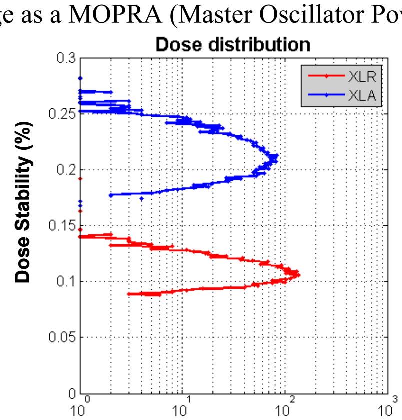

Figure 1 - Dose stability distribution comparing a conventional, dual chamber XLA laser with a ring technology XLR laser.

It is important to note that the system operates as a true regenerative amplifier – without an injected seed there is no output from the PRA subsystem. This multi-pass PRA dampens any input pulse instabilities from the MO chamber by running in "hard saturation", which results in previously unattainable low pulse to pulse energy stability. This evolutionary approach now allows the PRA to be optimized for an even higher state of saturation than other dual

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chamber designs thereby further reducing discharge instabilities that could adversely affect optical performance. While a conventional, dual chamber laser amplifies the MO pulse (seed) proportionally to its energy, the recirculating ring arrangement is less sensitive to the MO pulse variations. This effectively leads to a 1.5X increase in intrinsic pulse-to-pulse energy stability (Figure 1) and the same 1.5X improvement in dose stability that enables higher throughput with smaller scan windows.

HIGH POWER REQUIREMENTS

In order to successfully implement a higher power laser through the use of higher pulse energy, several considerations are needed. Foremost in such an approach is the development of optics that will not degrade prematurely with these higher fluences. The XLR 600i generates 15mJ pulses operating at 6kHz at the output, which in turn results in significantly higher fluences internal to the laser. Key power optics elements are exposed to peak irradiances on the order of $1MW/cm^2$. Dramatic improvements in CaF_2 substrate material were developed in close collaboration with the optics

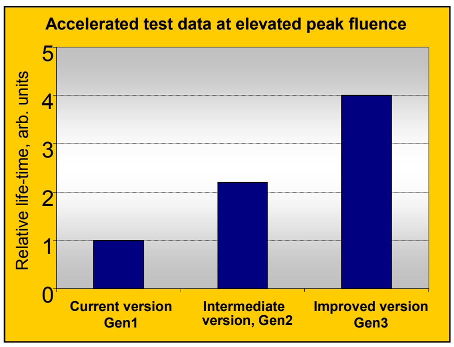

Figure 2 - Improvements in optics materials illustrated as relative lifetime performance during accelerated testing

suppliers to achieve greater surface damage resistance. The resultant materials were subjected to accelerated testing at high fluences to validate their greater immunity to surface damage (Figure 2).

In addition to surface damage considerations, polarization loss is also a risk factor with optics subjected to high fluences. Significant design efforts were put in place for the XLR 600i to mitigate such a phenomenon. Key improvements included the ability to avoid thermally induced birefringence in the high power optics components. The improvements can be quantified as polarization loss as a function of absorbed power, and are shown in Figure 3.

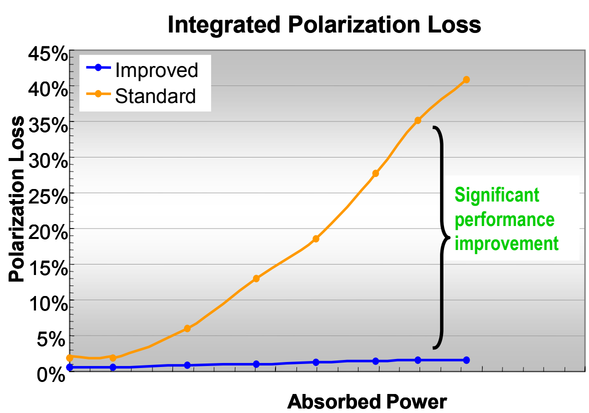

Figure 3 - Reduced polarization loss as a function of absorbed power using improved optics designs and materials.

OPTICAL PULSE DURATION AND BEAM UNIFORMITY

One of the main concerns in using higher energies to achieve higher average power, vs. using higher rep rates, for instance, is the potential for accelerated optics damage within and downstream of the laser. In this area, the ring architecture of the XLR design brings an intrinsic advantage, since it generates an inherently longer pulse duration. Coupled with additional pulse stretching built in to the laser system, a 50% increase in pulse duration is achieved compared to a conventional, dual chamber laser (Figure 4). This reduces the instantaneous peak power of the beam and distributes the energy over a longer period, providing a direct benefit to optics lifetime within and downstream of the laser. Assuming no additional pulse stretching in the scanner, a direct, 50% lifetime increase can be attained in the optics [some scanners include pulse stretching beyond the laser, resulting in a relative ~30% lifetime increase].

Furthermore, the multi-pass nature of the ring design leads to a more spatially uniform beam profile. This has a dramatic effect on energy distribution across the beam, as quantified by a peak energy density measurement.

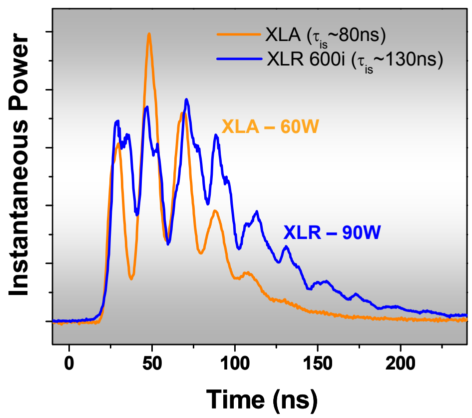

Figure 4 - Pulse duration comparison between a conventional, dual-chamber XLA (~80ns) vs. a ring architecture XLR (~130ns).

Typical peak energy densities that scanner lens designers require are well below 35 mJ/cm^2. If a conventional, dual chamber excimer laser were to be used, this limit could easily be reached. However, the XLR produces a beam of such uniformity, that the peak energy density of its 15mJ (90W) output results in a value (~25 mJ/cm^2) that is comparable to a conventional excimer operating at 10mJ (60W) output (Figure 5). This result, in combination with the longer pulse duration, minimize the risk of implementing a 15mJ, 90W solution as it relates to optics lifetime and reliability, both for the laser and the scanner.

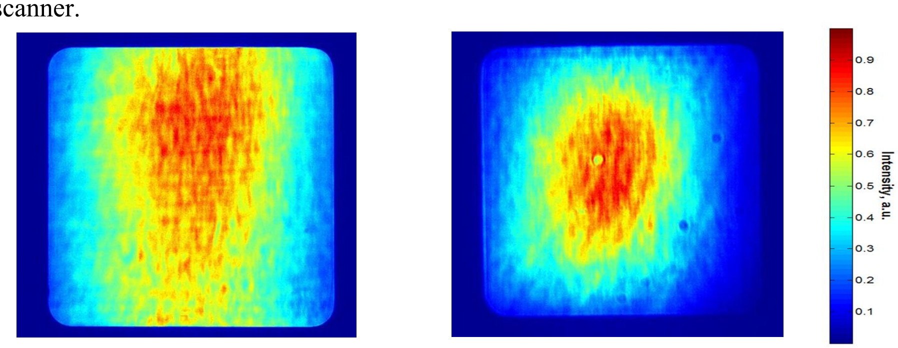

Figure 5 - 2-D intensity map of an XLR laser (left) and an XLA laser (right), showing a more spacially uniform energy distribution.

BANDWIDTH STABILITY

Considering that the application of such a high power laser will be in the 32nm node and below, high stability is of particular emphasis to meet the increasingly more stringent requirements of patterning uniformity. Key among them is bandwidth stability, due to its potential impact on CD uniformity (CDU).

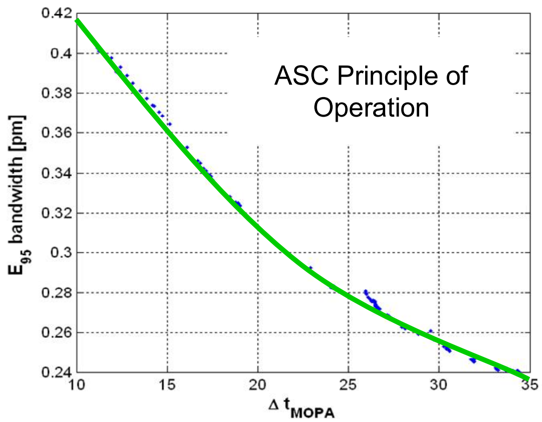

Figure 6 - Advanced Spectral Control (ASC) principle of operation: controlled timing differences between the MO and the PRA chamber firing (dtMOPA) enable the rapid modulation of E95 bandwidth to achieve short-term stability using closed-loop control with on-board metrology.

The XLR 600i includes Cymer's Active Bandwidth Stabilization (ABS) technology, an all-optical method that delivers sub-0.1pm long-term stability. This technology is part of the line narrowing module (LNM) that includes closed-loop control with the on-board E95 bandwidth analysis module. When used in combination with Advanced Spectral Control (ASC), a technique that modulates relative timing of the MO and PRA firing, a comprehensive short- and long-term stability solution is attained to stabilize bandwidth (Figure 6). Furthermore, the use of an optical method for ABS allows the extension of this capability to deliver a user-settable bandwidth target, aptly named tunable ABS.

SPECKLE CONTRAST

Finally, one of the significant improvements introduced on the XLR platform is a reduction in laser coherence, as characterized by speckle contrast. This is a characteristic unique to the ring architecture and has shown to reduce speckle

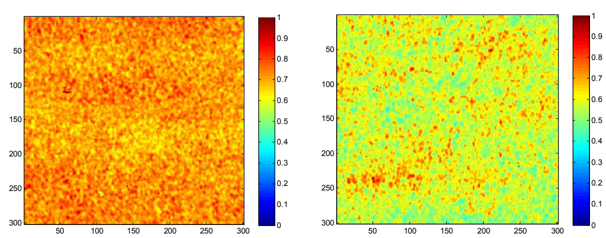

Figure 7 - Speckle contrast measurement for XLR (left) and XLA (right) showing a 30% reduction in contrast for the XLR relative to the XLA laser.

contrast by as much as 30%. Based on collaborative work published by Nikon, Inc.[2], a measurable improvement in line edge roughness (LER) and line width roughness (LWR) have been shown relative to a conventional, dual-chamber laser (Figure 7).

SYSTEM ENHANCEMENTS

While technological improvements drive optical performance parameters to meet the demands of advanced technology nodes, equally important are improvements in the system productivity, which can reduce scheduled downtime and enable overall higher wafer output. Such is the benefit of GLX™, a gas management technology that was introduced in 2007 to reduce the frequency of gas refills required to maintain stable performance. This same technology is embedded in the XLR 600i, resulting in a gas refill frequency of 1Bp compared to 100Mp of earlier-generation systems. This gas management technology has already been proven on fielded XLA-series, dual chamber lasers, demonstrating a dramatic increase in wafer output (>5000 wafer passes/year) for systems in high utilization. One of the added benefits of such a gas management technology is in the area of overall performance stability. As a result of achieving stable system performance over a longer gas life, optical performance parameters have also achieved a higher level of stability. As an example, physical beam parameters of pointing and position are shown throughout a 1Bp gas life indicating a very stable result (Figure 8).

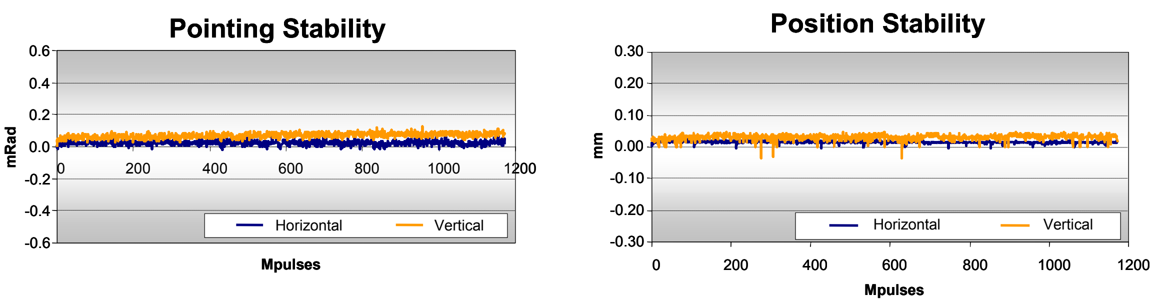

Figure 8 - Pointing and position stability of the XLR showing good stability with the GLX gas management technology.

SUMMARY

The need for higher power light sources to enable high throughput double patterning has been addressed with the introduction of the XLR 600i laser. Key performance characteristics include good energy stability to enable higher stage speeds and throughput, longer pulse durations and lower peak energy density to preserve optics lifetimes, and low laser coherence to minimize LER/LWR. Bandwidth stability has been achieved with a combination of short- and long-term stabilization technologies, ASC and ABS, respectively. Furthermore, to achieve higher scanner system output, the gas management technology, GLX, has been embedded with a resultant refill frequency of 1Bp.

[1] D. Brown, et al, "XLR 500i: Recirculating Ring ArF Light Source for Immersion Lithography", Proceedings SPIE, Feb 2007.
[2] T. Matsuyama, et al, "An Intelligent Imaging System for ArF Scanner", Proceedings SPIE, Feb 2008.